NON DESTRUCTIVE CHARACTERIZATION, INSPECTION, FAILURE ANALYIS OF ADVANCED COMPONENTS AND SENSORS WITH A HIGH RESOLUTION & HIGH CONTRAST MICROTOMOGRAPHY (microCT) SYSTEM

S H Lau*, Hauyee Chang, Joanna Cheong, Frederick Duewer, Michael Feser, Andrei Tkachuk, Wenbing Yun,
Xradia, Inc.
Concord, CA 94520.
Email contact:shlau@xradia.com

Abstract

3D X-ray microtomography (microCT) can non destructively characterize, inspect and solve many failure analysis problems associated with the manufacture of advanced materials, components, finished products, sensors for the military and industry. Conventional microCTs however, have spatial resolution limitation (typically of the order of a few microns to tens of microns) and poor contrast with low Z (atomic number) materials. We describe the role of a novel high resolution and high contrast microCT to visualize defects at the micron and sub-micron length scales, typically encountered in the manufacturing and development of advanced sensors and polymer composites. Examples shown include semiconductor packages, low temperature co-fire ceramics (LTCC), and Laser fusion targets spheres.

1.0 Background

Computer tomography (CT) has been used for several years in the medical community for non invasive x-ray imaging of the human anatomy. The same technique is applied to non destructive inspections of parts and components where the object can be viewed in 3D (Figure 1) and selected CT virtual slices (cross sections) can be made at different planes to reveal the internal structures (Figure 2).

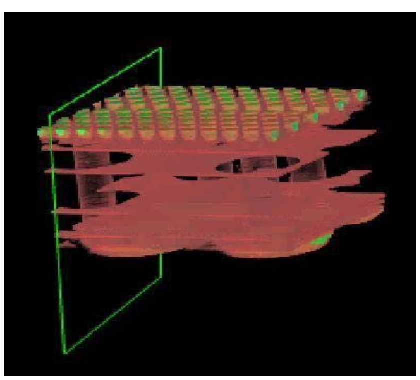

Figure 1 : 3D rendered image of a microelectronic flip chip package

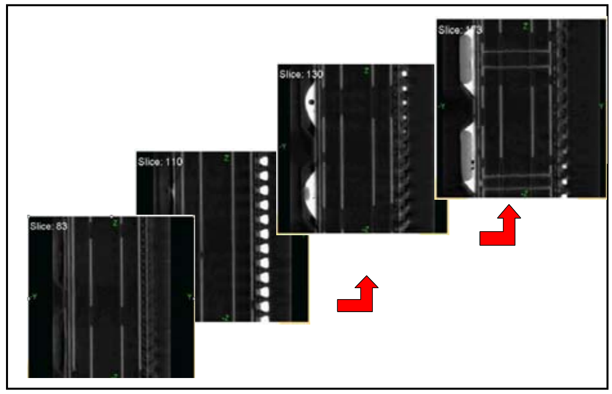

Figure 2: Virtual cross sectioning of the flip chip, showing the internal structure slice by slice without the need for physical or chemical deprocessing

MicroCT has the advantage over conventional imaging tools such as optical microscopy and electron microscopy since it can image surface and buried structures without sample preparation, vacuum requirement or physical deprocessing.

While conventional microCTs are currently being used for bio-medical[1-2], material, industrial research[3] and microelectronic[4] inspections, they suffer from two major drawbacks, namely spatial resolution limitation and an inherently poor contrast with low Z materials. Spatial resolution (based on Raleigh criteria) of most conventional industrial or bio-medical microCTs range from a few microns to tens of microns[5]. With the continual trend towards miniaturization and weight reduction of sensors, packages and advanced materials, defects are getting smaller, and those < 5 microns are often not detected readily.

Contrast in transmission x-ray imaging is predominantly based on absorption differences or attenuation length differences of material within the sample. While reasonable contrast can be observed, say for solder balls or Cu/ Au wires in a standard polymer

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microelectronic package, however, in many advanced packages and sensors, the region of interest is often within a matrix of low z materials like Si, polymer, and composites. As such, the attenuation length differences between materials in the region of interest can be very small, resulting in little or no contrast in the image.

By incorporating proprietary optics, in this paper we describe some of the results of the Xradia MicroXCT system that is able to achieve spatial resolution of 1 µm or better, and with high contrast, regardless of the composition of the sample matrix.

2.0 System Overview

The schematic of the Xradia MicroXCT system configuration is depicted below. (Figure 3).

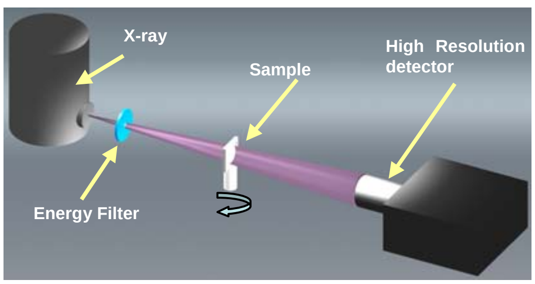

Figure 3: Schematic of the MicroXCT

A commercial closed source microfocus x-ray tube with 150 kV and focal spot of around 5 µ is used. The object can be translated in x-y-z directions in a high resolution precision stage, vibration isolated on a granite base. High resolution and high contrast capability is achieved with proprietary x-ray imaging and detector optics, with a 16 bit CCD camera, available in 1024x1024 or 2048x2048 pixel resolution. (Figure 4).

The principles behind the high resolution, artifact free tomography MicroXCT system were described hearlier in another paper[6].

2.1 Applications

Harnessing the penetrating power of a 150 KeV (or higher) x-ray source, imaging a whole sensor or multiple components embedded within a hard protective casing is feasible. These include 2D and 3D visualization of the internals of a whole semiconductor package, MEMs, miniature sensor, components, and other advanced materials.

Figure 4: Xradia MicroXCT

Higher resolution is achieved by zooming in the region of interest at higher magnification. Other potential applications of the tool include the examination of overt or covert sensors, components, smart materials of military significance from friendly or hostile nations, without physical cross sectioning or material deprocessing.

2.1.1 Advanced Semiconductor Package Failure Analysis

Solder ball cracks, micro voids, die delamination, die cracks, substrate via cracks, metal migration, wire shorts and open, in advanced semiconductor packages, like flip chip and multi-stacked dies can be routinely imaged non destructively with the high resolution microCT.

The following is a failure analysis example to locate defects under a solder ball in an advanced semiconductor package.

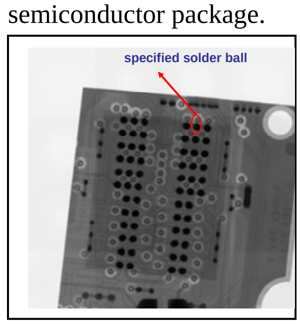

Figure 5: Possible failure location is isolated to a solder ball of interest. 2D x-ray image shows the layout of the semiconductor package

Without resorting to destructive physical cross sectioning and imaging with a SEM (scanning electron microscope), the defect was identified with the MicroXCT to be the result of cracks in the substrate

below the solder ball (Figures 6-7). As the failure is located in the thin Cu traces within the low Z substrate, such cracks are too small and difficult to be imaged with conventional microCTs and may also be difficult to locate using destructive physical cross sectioning techniques.

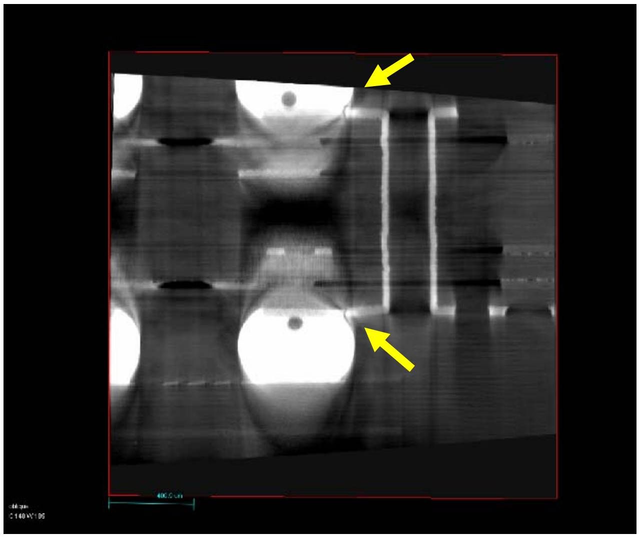

Figure 6: CT slice (virtual section at x-y plane) showing cracks just below solder balls

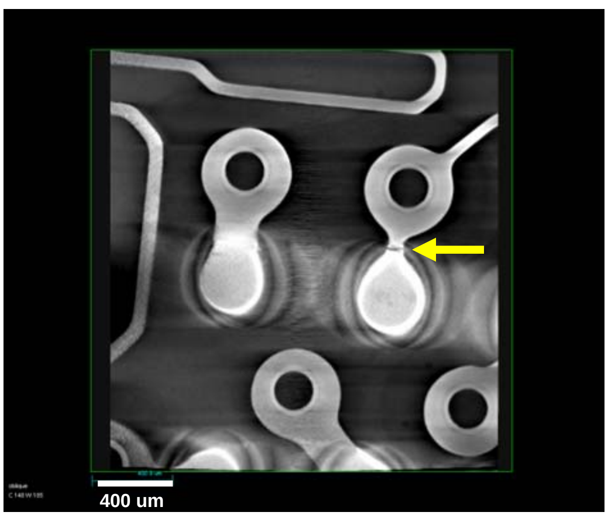

Figure 7: CT slice (virtual section at x-z plane) showing cracks in Cu trace in substrate just below the solder ball.

2.1.2 Low Temperature Co-fire Ceramic (LTCC)

Microwave and millimeter-wave multichip module (MCM) packaging is an emerging technology that is of great significance for both defense and commercial applications. Military applications covering radar, electronic warfare, communications and smart munitions, and commercial applications such as telecommunications, cellular radio, direct broadcast satellite, personal communication systems (PCS) and intelligent transportation systems (ITS), all require microwave and millimeter-wave electronics.

Advances made in both hard and soft lamination technologies such as low temperature co-fire ceramic (LTCC), high temperature co-fire ceramic (HTCC), and polymer materials have resulted in high-density routing and interconnections for microwave circuits. These technologies offer the potential to reduce or eliminate wirebonds, increased reliability, improved yield, and lower fabrication costs., making them attractive for adoption in military and commercial applications.

Notwithstanding there are still metrology challenges in the manufacture of these new laminated packages. For example there are currently no good known methods to adequately characterize voiding, and delamination between interfaces of the metal thermal spreader, LTCC substrates and other components.

The following are examples demonstrating the use of high resolution and high contrast microCT, to solve some of these characterization issues in LTCC packages, typically used in next generation airborne phased array radars. (Figures 8-10)

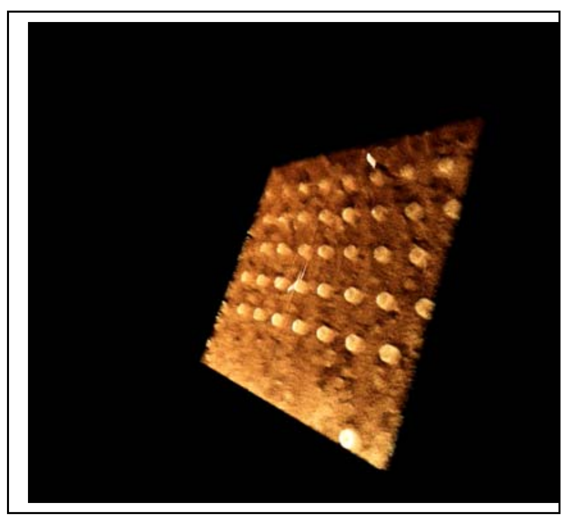

Figure 8: Rendered 3D image showing the tall via structures of LTCC package

The attractive feature of such non destructive imaging is that voids and delamination between the interfaces of the metal (Au/Sn) and LTCC substrate can be easily seen by making a CT slice at the critical region of interest. Via alignment, dimensions and

layout of the various components within the package can be verified and measured with the MicroXCT.

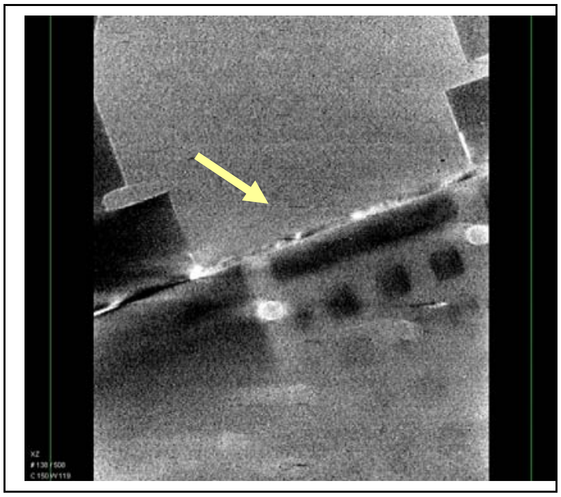

Figure 9: CT section clearly reveals voids between connector and substrate

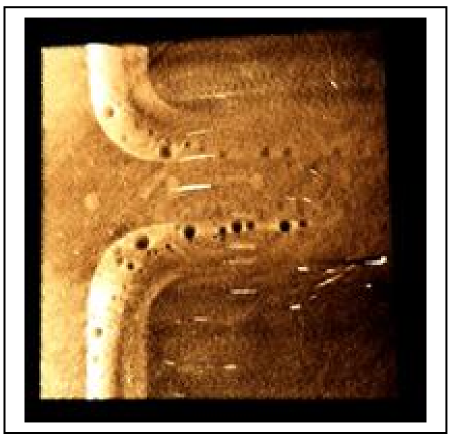

Figure 10: CT section at interface of a hermetic seal, showing voids between the metal and LTCC substrate

2.1.3 Imaging Very Low Contrast Materials

Another limitation with conventional x-ray absorption technique is its inherently poor contrast when imaging low Z materials in a matrix of other low Z materials. These include polymers, bio materials and composites, which are typically used in ultra light weight, tough fabrics, armor, artificial muscles, membranes and laser fusion targets. With proprietary optics and phase contrast techniques, even ultra low Z polymers and materials can be imaged with excellent resolution and contrast.

We illustrate this with examples from laser fusion targets, used in inertial confinement fusion (ICF) and high energy density physics (HEDF). Fabricating these millimeter sized targets with micrometer structures to tolerances required is highly challenging for the ICF and HEDF community. (Figure 11) is the typical schematic of a double shelled spherical target, while (figure 12) is a CT slice of the predominantly low Z double shell target sphere, obtained with the Xradia MicroXCT.

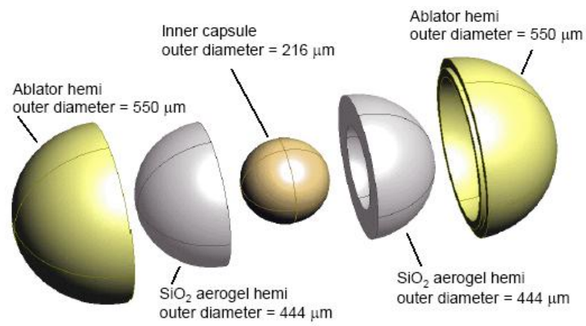

Figure 11: Schematic of the components that make up a double shell fusion target. Source: "Development of a Manufacturing Process for Double Shell targets ", a Lawrence Livermore National Lab poster. UCRL-POST-209776, M Bono, et.al

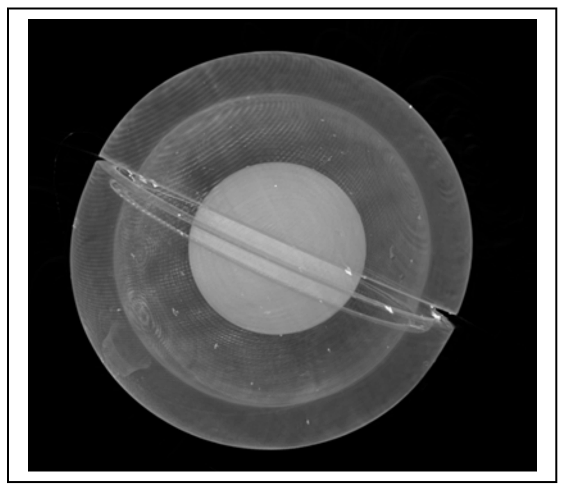

Figure 12: Laser fusion target sphere showing outer epoxy Ablator shell and innermost glass capsule core (which is surrounded by SiO2-aerogel foam). Materials are all low z, but contrast is sufficient to differentiate the individual boundaries with fine details. The spacing between the two Ablator hemi(s) is shown to be out of tolerance. Sample courtesy: Los Alamos National Laboratory`

The next example, demonstrates the MicroXCT imaging capability for Be (Beryllium) disc (Atomic # 4) an ultra low Z material, used in such target fabrication. Here a sub-micron sized crack can be clearly seen at the orifice of the disc (Figure 12).

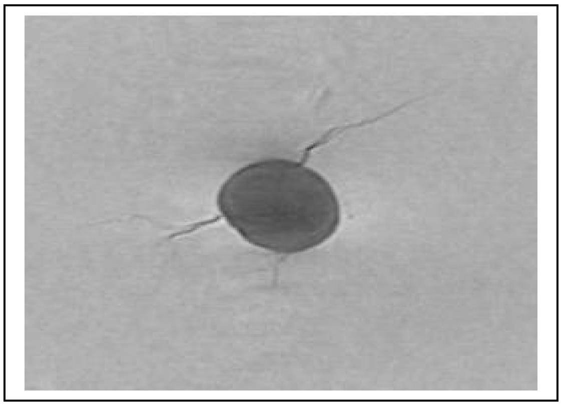

Figure 12: Beryllium disc, showing sub-micron size cracks on orifice (Diameter of orifice is about 40 microns).

3.0 Conclusion

Compared with conventional microCTs and other imaging techniques, the novel microtomography system we have described is well positioned to meet the metrology challenges of next generation component manufacturing. Using a few “difficult” samples as examples, it has been demonstrated that failure analysis, inspection and characterization of advanced components, sensors and materials can be evaluated non invasively, with good imaging quality, spatial resolution and contrast.

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